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RESEARCH DEPARTMENT

Image-transfer standards conversion: modulation due to a difference between field frequencies

RESEARCH REPORT No. T-130

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THE BRITISH BROADCASTING CORPORATION
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RESEARCH DEPARTMENT

**IMAGE-TRANSFER STANDARDS CONVERSION:
MODULATION DUE TO A DIFFERENCE BETWEEN FIELD FREQUENCIES**

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(1964/49)

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SUMMARY

When an image-transfer television standards converter is used to convert from one standard to another having a different field frequency the video output will be amplitude-modulated by a waveform whose frequency is the difference between the two field frequencies. As a result of this, pictures on the new standard will flicker at the modulation frequency. An earlier study¹ of the nature and amplitude of this modulation was based upon idealized camera and cathode-ray tube characteristics; this report describes graphical and algebraic methods of calculating the modulation waveform which take into account recent detailed measurements of the performance of the C.P.S. Emitron camera tube.

The calculated and measured modulations are compared for the particular case of a C.P.S. Emitron camera tube and a cathode-ray tube having a Willemite phosphor.

1. INTRODUCTION

An image-transfer standards converter consists, basically, of a cathode-ray tube which displays the picture on the scanning standards of the incoming signal and a camera, operating on the scanning standards of the outgoing signal, which views the display. If the field frequencies of the two standards are different, the charge accumulated on the camera-tube target will vary from one camera field period to the next. This is because the light output from any part of the display phosphor is not constant but reaches a maximum value while bombarded by the scanning beam and decays steadily when the beam has moved on. When the camera is operating at a higher field frequency than the display, there will be occasions when a point of the camera target is scanned twice between two consecutive illuminations of the corresponding point of the display tube, resulting in an abnormally low output from the camera at the second of these scans. On the other hand, when the camera is operating at a lower field frequency than the display, there will be occasions when a point on the display tube is illuminated twice between two consecutive scans of the corresponding point of the camera target, resulting in an abnormally high output from the camera at one scan. The video signal from the camera will thus be amplitude modulated at a frequency equal to the difference between the field frequencies of the input and output scanning

standards; the precise form and amplitude of the modulation will depend upon the display-tube afterglow characteristic and the camera-tube storage and discharge characteristics.

The amplitude and waveform of the output modulation for a stationary input picture were first calculated by A.V. Lord.¹ He simplified the calculation by assuming that the decay characteristic of the display-tube phosphor could be represented approximately by an exponential waveform with a suitable time-constant and that the camera tube was ideal, i.e. the charge on an element of the target grew at a rate proportional to the brightness of the corresponding part of the scene, was stored without loss, and was rapidly and completely neutralized by the scanning beam once in every field.

The following analysis is an extension of Lord's method using the measured decay characteristic of a typical display tube phosphor² and the storage and discharge characteristics of the C.P.S. Emitron camera tube.³ The calculated modulation waveforms were compared with the measured waveforms for conversions between standards having field frequencies of 50 c/s and 60 c/s respectively.

2. THE CALCULATION OF THE MODULATION AMPLITUDE

2.1. General

The modulation was determined from the measured characteristics of the display tube and the camera, assuming that the vertical resolution of the display was adjusted to remove the line structure of individual fields, so that when the display-tube beam current was constant, each point of the display could be regarded as equally excited once during every field instead of being excited once in every picture.

The variation in brightness of a point on the display tube was derived from the measured response of the tube to a single short-duration excitation.²

The output signal from a C.P.S. Emitron camera tube has been measured during several successive field scans following an exposure lasting a small fraction of a field period.³ Furthermore, it has been shown that the measured output produced by constant illumination for a larger portion of a field period was very similar to that computed by using the previous result. In the present computation, the illumination was treated as though it were made up of a number of shorter flashes, and it was assumed that the contribution of the illumination of the target during one field to the output two or more scans later was independent of the illumination during the intervening period and that all such contributions could be added linearly. The same method was used to compute the response to a continuous illumination which varied in brightness.

The integration of all the contributions to the outputs from the camera at each scan was done in two ways:

- (a) by drawing waveforms of illumination and camera output accurately to scale and measuring the areas under them. (Graphical method).

- (b) by reading off the heights of the curves at regular intervals and assuming the areas to be divided into strips whose areas were calculated and added. (Arithmetical method).

These methods are described in sub-sections 2.2.1. and 2.2.2. An algebraic analysis follows in sub-section 2.3.

2.2. Graphical and arithmetical methods

2.2.1. The integration of the phosphor afterglow curve

The brightness of the phosphor of a display tube after an impulsive excitation, such as occurs when a point is scanned by an electron beam, is of the form shown as curve (a) of Fig. 1. This curve is shown divided into sections at the points C, D, E, F, G, etc., each section being one display field period (T_W) in length with the first section starting at $t = 0$. If a point on the phosphor is periodically scanned the instantaneous brightness of that point at any instant (other than that at which it is being excited by the electron beam) is the combined afterglow of all the previous scans. Under normal conditions, this is equal to the sum of brightnesses which would have resulted at that time from each of the scans considered separately, and the resulting brightness/time curve will be of the form shown by curve (b). Thus at the moment 'T' which is t milliseconds after the last passage of the beam the brightness will be made up of a component b_1 due to the latest scan, b_2 due to the previous scan, b_3 , b_4 , etc., from earlier scans. Under the condition of repeated scanning, the brightness of a point of the phosphor will vary at scanning frequency, the waveform of each cycle being the sum of all the sections, CD, DE, etc., of the single-impulse decay curve.

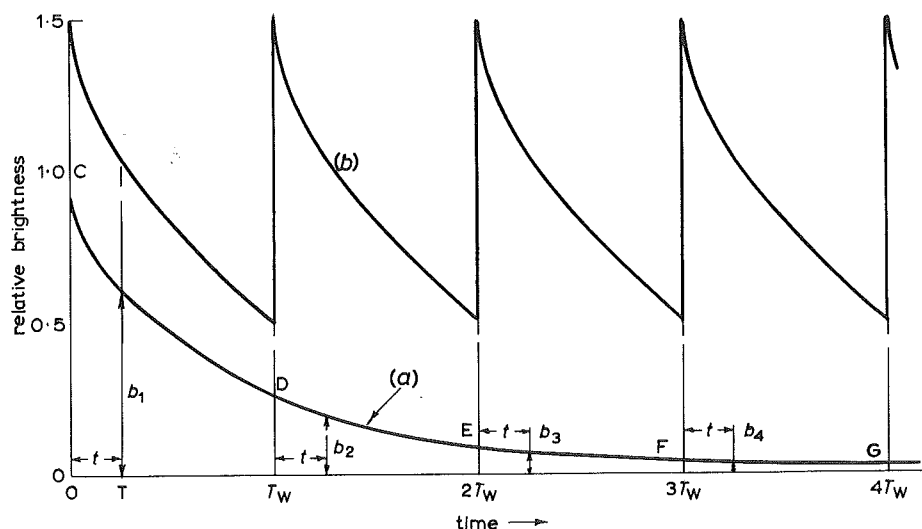


Fig. 1 - Decay characteristics of display tube phosphor
(Diagrammatic - not to scale)

- (a) Unit impulse excitation
(b) Periodic scanning

It is clear that the difference between the maximum and minimum ordinates of curve (b) is equal to the maximum ordinate of curve (a) and that the area under one cycle of curve (b) is equal to the area under the whole of curve (a). If the field frequency were to be increased in the ratio $1 : n$, keeping the same number of lines, the velocity of the scanning spot would increase in the same ratio. As a result, the brightness due to one excitation of the phosphor, which is the maximum ordinate of the curve (a) and the difference between the maximum and minimum ordinate of curve (b), would decrease in the ratio $n : 1$. At the same time, the area under one cycle of curve (b), which is equal to that under the whole of curve (a), has been reduced in the ratio $n : 1$. The number of cycles per second has, however, increased in the ratio $1 : n$ so the mean brightness remains unaltered. Combining the two results, the ratio of the peak-to-peak variation in brightness to the mean brightness varies inversely as the display field frequency.

2.2.2. The graphical determination of the output from an ideal camera

If the optical system were perfect, curve (b) of Fig. 1 would also represent on suitable scales the waveform of the illumination of a point on the camera target or photocathode and therefore the waveform of the photo-electric current emitted from that point. This has been re-drawn in Fig. 2.

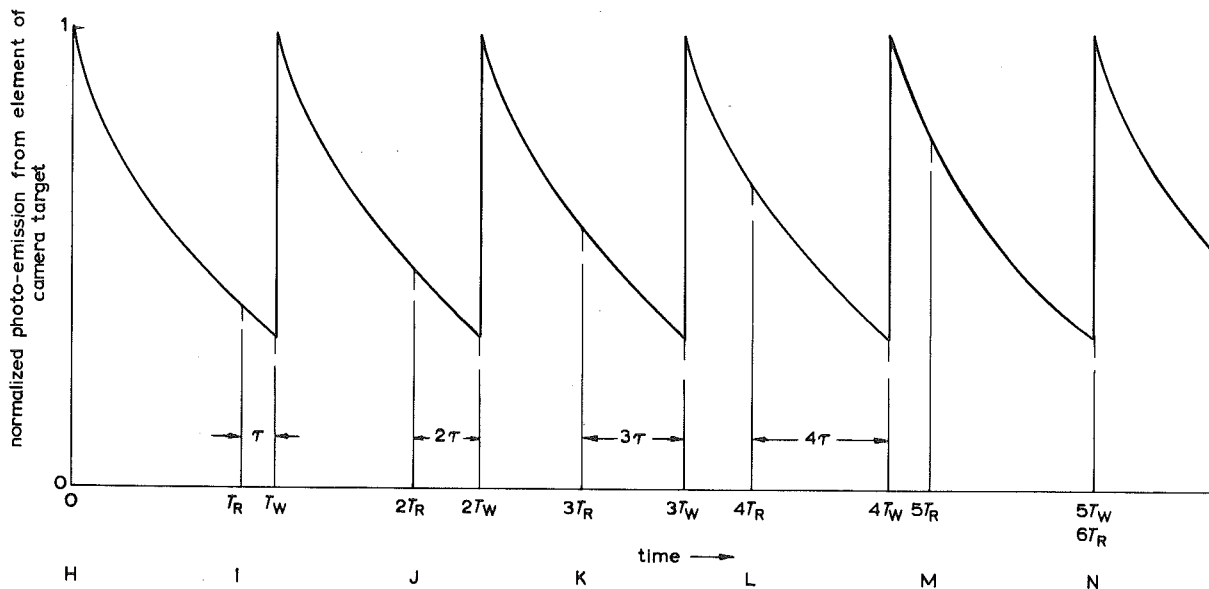


Fig. 2-Relative timing of writing and reading used in determining the flicker modulation for 50 c/s to 60 c/s conversion

The target element is discharged once every reading field, for example at the times marked H, I, J, K, L, etc., in Fig. 2 where the reading field period, T_R , has been taken as being shorter than the display field period, T_W . If the camera were perfect, the signal outputs at the times I, J, K, etc., would be proportional to the areas under sections HI, IJ, JK, etc., of the curve of Fig. 2.

As the first step in the graphical calculation of the modulation waveform from a standards converter using an ideal camera, the display-tube phosphor character-

istic for impulse excitation was drawn accurately to scale and the curve for periodic scanning at 50 fields per second ($T_W = 20$ ms) was derived from it. Next the instants at which a selected target element would be discharged by a 60 c/s scan, ($T_R = 16.2/3$ ms), were marked on this in the phasing shown in Fig. 2. The area under each section of the curve was then measured with a planimeter.

The six measured areas cover between them one modulation cycle, and these values, representing camera signal currents at each moment of discharge, were used to plot curve (a) of Fig. 10. The phasing of Fig. 2 was chosen so that the area under the first section of the curve, OI, would have the largest possible value; this also gave the area under the sixth section, MN, the smallest possible value (marked N), so this phasing enabled the two extreme values of signal output to be obtained. If the shape of the modulation curve had been required in more detail, additional plotting points for other phases could have been obtained by moving the phase of the reading fields relative to the writing fields. It is, however, easy to see that the curve must be continuous, apart from discontinuities of slope at the maximum and minimum points.

The brightness modulation curve for the display tube scanned at 60 c/s was derived in a similar manner to that described for 50 c/s scanning. This curve is shown as the camera target excitation curve in Fig. 3, where the timing of the 50 c/s reading field scans is also marked. The areas under each section of an accurately plotted curve were measured with a planimeter giving five points from which the modulation curve was plotted (curve (a) of Fig. 11).

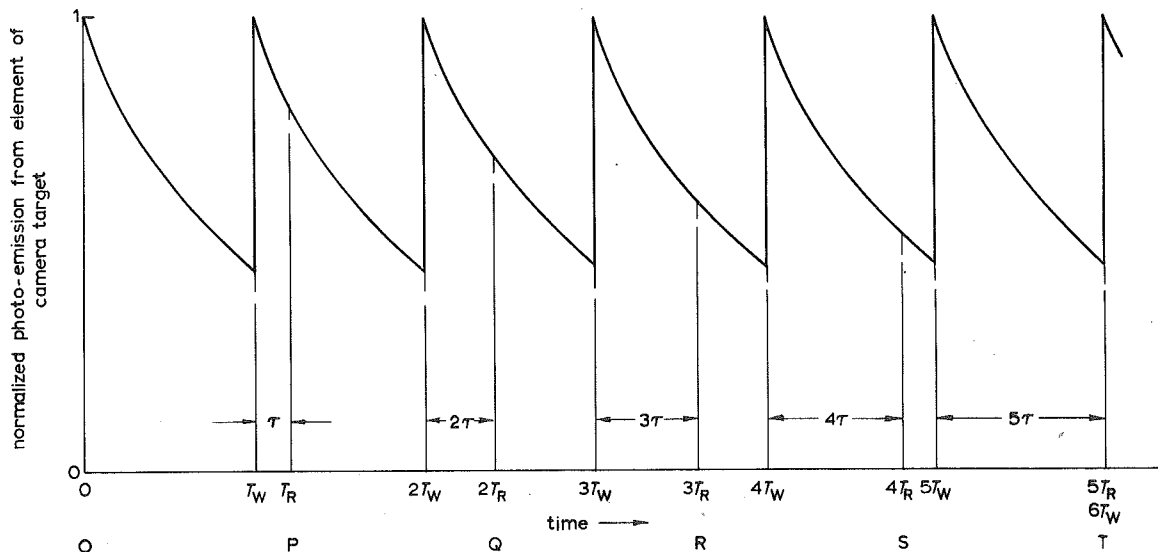


Fig. 3 - Relative timing of writing and reading used in determining the flicker modulation for 60 c/s to 50 c/s conversion

2.2.3. The effects of the camera characteristics

The amplitude of the signals from a C.P.S. Emitron exposed to a short pulse of illumination depends on the delay between exposure and the first scan of the point.

This is shown in Fig. 4 where the upper curve (a) shows the first scan output falling with increasing delay between exposure and scanning and the lower curve (b) shows a related rise in second scan output. The outputs from the third and subsequent scans after illumination are similar in character to the second scan output but have progressively lower levels.

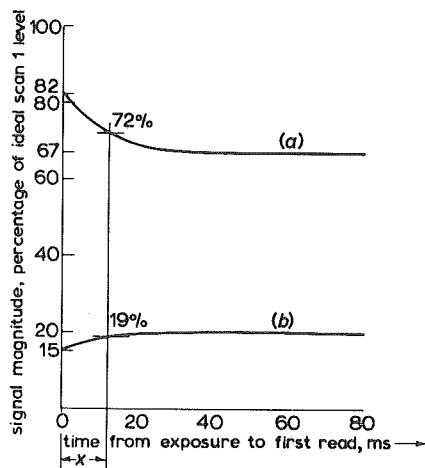


Fig. 4 - Imperfect storage and erasure in a camera tube

- (a) 1st read
- (b) 2nd read

contributes to the discharge x ms later. The height of point Y on the curve (a) of Fig. 5 was therefore multiplied by 0.72 to give the point Z. Similarly, all the points of curve (a) of Fig. 5 were modified, to give curve (b). The areas under sections OP, PQ, etc., of this curve represent the outputs from the camera due to the first scanning of the stored charge.

The illumination waveform, curve (b) of Fig. 1, has been re-drawn as curve (a) of Fig. 5. If the illumination is regarded as a series of abutting short duration pulses, it is clear that those light pulses which occur some time before the first erasure will contribute less to the output, in proportion to their amplitude, than those pulses which occur immediately before erasure. Consider, for instance, the illumination represented by Y, in Fig. 5, x ms before erasure at R. Curve (b) of Fig. 4 shows that only 72% of the charge due to this illumination

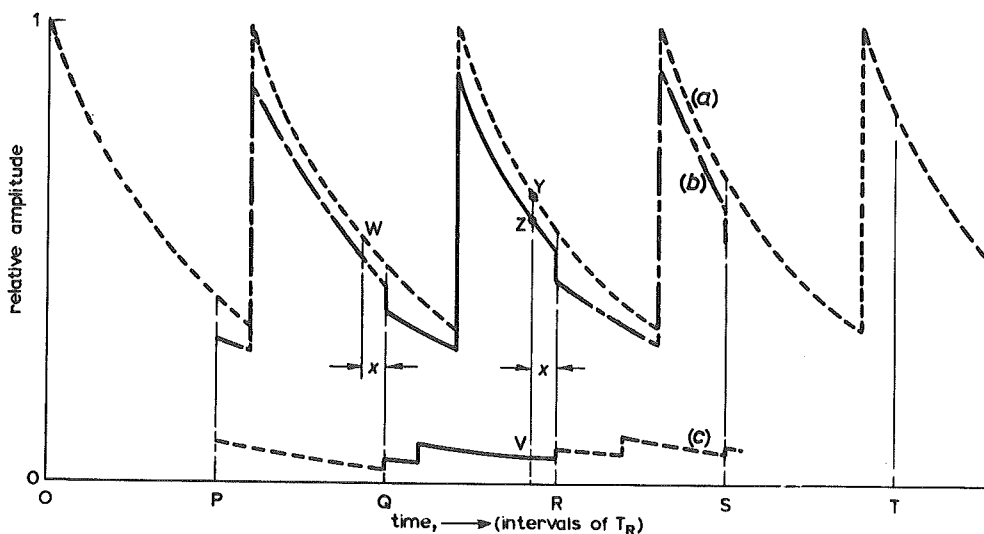


Fig. 5 - The determination of flicker modulation, C.P.S.E. camera (50 c/s to 60 c/s conversion)

- (a) Excitation of camera target
- (b) Contribution to output from 1st scanning of charge
- (c) Contribution to output from 2nd scanning of charge

The output at R also includes a component resulting from the second scan of the charge due to the illumination during the previous reading field. This 'second scan' contribution will be the resultant of the section PQ of the illumination curve, (a) of Fig. 5, modified by curve (b) of Fig. 4. Considering the point W, Fig. 5, which occurred $(x + T_R)$ ms before R, Fig. 4(b) shows that the second scan component is 19% of the total output due to the illumination represented by W. The height of this point was therefore multiplied by 0.19 to give the height of the point V which is marked below the points Z and Y. Similarly, the heights of all the points on curve (a) are multiplied by the corresponding values of the curve (b) of Fig. 4 and delayed by one reading field to give the curve (c) of Fig. 5.

The total output at time R is then proportional to the sum of the areas under curves (b) and (c) of Fig. 5 between Q and R. Similarly, the outputs corresponding to P, Q, etc., may be found by summing the areas under curves (b) and (c) during the preceding field periods. The sums thus obtained are used to plot the conversion modulation curves.

The curves of Fig. 5 for the 50 c/s to 60 c/s conversion were drawn accurately to scale and the areas measured with a planimeter, giving six plotting points from which to draw curve (b) of Fig. 10. Similar curves were drawn and measured for conversion from 60 c/s to 50 c/s leading to curve (b) of Fig. 11.

It has already been shown that curves (a) of Figs. 10 and 11 each exhibit two discontinuities of gradient in each cycle. The abscissae of these are 0 and 16.2/3 ms in Fig. 10 and 0 and 20 ms in Fig. 11. It may be shown that curves (b) exhibit three discontinuities of slope in each cycle, occurring at 0, 16.2/3 and 33.1/3 ms in Fig. 10 and at 0, 20 and 40 ms in Fig. 11.

2.2.4. The arithmetical method

This followed the graphical method very closely, the main purpose of using both methods was in order that each should provide a check on the accuracy of the other. The areas under the curves were found by summing ordinates instead of by the planimeter method described in the previous sections. The results obtained by the arithmetical process were usually slightly higher than those found graphically, but even so they usually agreed within $\pm 1\%$ and never differed by more than 2%. When working to this order of accuracy, neither method has a marked advantage over the other, but if the basic data had been of a more precise nature, the arithmetical method would be more easily refined to give a corresponding improvement in the accuracy of the results.

2.3. The algebraic representation of the modulation waveform

In the previous section methods have been described for calculating the modulation amplitude arising when the conversion is between two specified field frequencies and when the display and camera tube characteristics are known in graphical form. In this section these characteristics will be represented by the sums of exponential waveforms and simplifications will be made leading to a diagram (Fig. 8), which enables an estimate to be made of the modulation arising under a wide range of conditions.

2.3.1. Calculation of the light output from the display tube

The decay of light output from the phosphor of a display tube after a short pulse of beam current at $t = 0$ may be written in the form:

$$\begin{aligned} b(t) &= a_1 e^{-\alpha_1 t} + a_2 e^{-\alpha_2 t} + a_3 e^{-\alpha_3 t} + \dots \text{etc.} \\ &= \sum a_r e^{-\alpha_r t} \end{aligned}$$

where $b(t)$ is the brightness at time t after the current impulse,

$\alpha_1, \alpha_2, \alpha_3, \dots$ are the reciprocals of the time constants of the exponential components into which the total brightness has been resolved,

and a_1, a_2, a_3, \dots are the initial amplitudes of the exponential components. The peak brightness, b_0 , is equal to $a_1 + a_2 + a_3 + \dots \text{etc.}$

Consider a small area of phosphor on the screen of the cathode-ray tube scanned by a normal raster. The excitation of this area is repeated at the display field frequency of period T_w , so that each cycle of curve (b) of Fig. 1 is made up of the sum of sections of curve (a), as described in section 2.2.1. The area under one cycle of curve (b) must be equal to the area under the whole of curve (a), i.e. it is:

$$\int_0^{\infty} \left(\sum a_r e^{-\alpha_r t} \right) dt = \sum \frac{a_r}{\alpha_r}$$

The equation of a cycle of curve (b) can be found by noting that the values at any instant of the contributions from all the sections of any one exponential component of curve (a) form a geometrical progression with common ratio $e^{-\alpha T_w}$. The value of the contribution from the first section at time t after the latest illumination is $a_r e^{-\alpha_r t}$ so the sum of the contributions from an infinite number of sections of the component is

$$\frac{a_r e^{-\alpha_r t}}{1 - e^{-\alpha_r T_w}}$$

The equation of a cycle of curve (b) is then:

$$B(t) = \frac{a_1 e^{-\alpha_1 t}}{1 - e^{-\alpha_1 T_w}} + \frac{a_2 e^{-\alpha_2 t}}{1 - e^{-\alpha_2 T_w}} + \frac{a_3 e^{-\alpha_3 t}}{1 - e^{-\alpha_3 T_w}} \text{ etc.}$$

which can be written $B(t) = A_1 e^{-\alpha_1 t} + A_2 e^{-\alpha_2 t} + A_3 e^{-\alpha_3 t} + \dots + A_r e^{-\alpha_r t} \dots \text{etc.}$

$$\text{where } A_r = \frac{a_r}{1 - e^{-\alpha_r T_w}}$$

and the peak brightness is $B_0 = A_1 + A_2 + A_3 \dots \text{etc.}$

2.3.2. Modulation due to a conversion from a lower to a higher field frequency assuming that the camera is ideal.

When the conversion is from a lower to a higher field frequency the reading field period, T_R , is shorter than the writing field period, T_W , the difference being $\tau = T_W - T_R$. The charge on an element of the target just before a reading scan is represented, in Fig. 6, by the area enclosed by the heavy line. In section 2.2 one

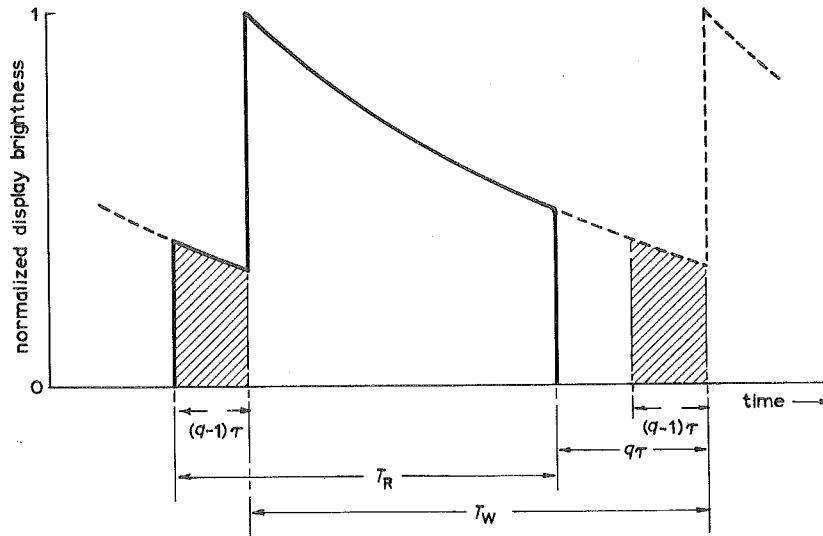


Fig. 6 - Calculation of the output of the q th field, 50 c/s to 60 c/s conversion

— Boundary of area representing charge on target element at instant reading
 // Equal areas

of the computed points was chosen to correspond to that phase relationship at which reading occurred immediately before a writing point, and the outputs were found on the first, second, third, etc., reading scans after this reference condition. It was also assumed, for convenience of description, that the writing and reading field frequencies were exactly in the ratio 50 : 60 so that the output amplitude varies cyclically over an integral number of both writing and reading field periods. In a practical converter the writing and reading scans may be in any one of a range of phase relationships and in order to make this analysis general it is convenient to define the q th reading scan as the one occurring $q\tau$ before the next writing scan where q is not restricted to integral values. If q is less than unity, the q th reading field does not include the moment at which the illumination of the target element rises rapidly. The maximum value of q is T_W/τ which need not be an integer.

It is seen from Fig. 6 that the charge Q_q read off by a perfect camera at the q th scan is given, for values of q equal to or greater than 1, by:

$$Q_q = \int_0^{T_W} B(t) dt - \int_{T_W - q\tau}^{T_W - (q-1)\tau} B(t) dt$$

Let these integrals be called I_1 and I_2 , so that $Q_q = I_1 - I_2$. I_1 is independent of q . Since I_2 includes q it contains the modulation component; it is given by:

$$I_2 = \int_{T_w - q\tau}^{T_w - (q-1)\tau} B(t) dt = \sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} (1 - e^{-\alpha_r \tau}) e^{q\alpha_r \tau}$$

When q lies in the range 0 to 1.

$$Q_q = \int_{(1-q)\tau}^{T_w - q\tau} B(t) dt = \sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} (e^{\alpha_r (T_w - \tau)} - 1) e^{q\alpha_r \tau}$$

In both of these expressions, q only appears in the terms $e^{q\alpha_r \tau}$, so for values of q between 0 and 1, the graph of Q_q against q rises and is concave upwards and for the remainder of the modulation cycle, the curve falls and is convex upwards, the sign before I_2 being negative.

The maximum and minimum values of the output from an ideal camera can be found by using either of these formulae and putting q equal to the extreme values of the range in turn, i.e. by putting $q = 1$ and $q = T_w/\tau$ into the formula which applies when q is greater than 1, or putting q equal to 0 and 1 in the other formula.

Using this second method:

$$Q_0 = \sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} [e^{\alpha_r (T_w - \tau)} - 1]$$

$$Q_1 = \sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} [e^{\alpha_r (T_w - \tau)} - 1] e^{\alpha_r \tau}$$

The difference between them is:

$$\sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} (e^{\alpha_r (T_w - \tau)} - 1) (e^{\alpha_r \tau} - 1)$$

$$= \sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r \tau}) (1 - e^{-\alpha_r (T_w - \tau)})$$

The mean of maximum and minimum output is:

$$\frac{1}{2} \sum \frac{A_r e^{-\alpha_r T_w}}{\alpha_r} (e^{\alpha_r (T_w - \tau)} - 1) (1 + e^{\alpha_r \tau})$$

$$= \frac{1}{2} \sum \frac{A_r}{\alpha_r} (1 + e^{-\alpha_r \tau}) (1 - e^{-\alpha_r (T_w - \tau)})$$

Then the proportion of ripple to output, expressed as the ratio:

$$\frac{\text{d.a.p. ripple}}{\text{mean of extreme outputs}} \text{ is } 2 \frac{\sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r \tau}) (1 - e^{-\alpha_r (T_w - \tau)})}{\sum \frac{A_r}{\alpha_r} (1 + e^{-\alpha_r \tau}) (1 - e^{-\alpha_r (T_w - \tau)})}$$

For the particular case of a simple exponential decay of the phosphor brightness this reduces to $2 (1 - e^{-\alpha \tau}) / (1 - e^{-\alpha (T_w - \tau)}) = 2 \tanh \frac{1}{2} \alpha \tau$ where α is the value of α_r for the single component present.

The full-line curves on the right-hand half of Fig. 8 show this ratio plotted against the ratio τ/T_w for four values of αT_w ; 1, 2, 5 and 6.2/3.

(The values $\alpha T_w = 1, 2$ and $6.2/3$ were chosen so that $1/\alpha$ is 20 ms, 10 ms and 3 ms respectively when the display field frequency is 50 c/s. Time-constants of about 10 msecs are in operational use while 3 msecs represents the longest afterglow time-constant which will not in itself blur the portrayal of moving objects.)

2.3.3. Modulation due to conversion from a higher to a lower field frequency

A similar technique can be applied to the case of a camera field frequency which is lower than the display field frequency. From Fig. 7 it is seen that the

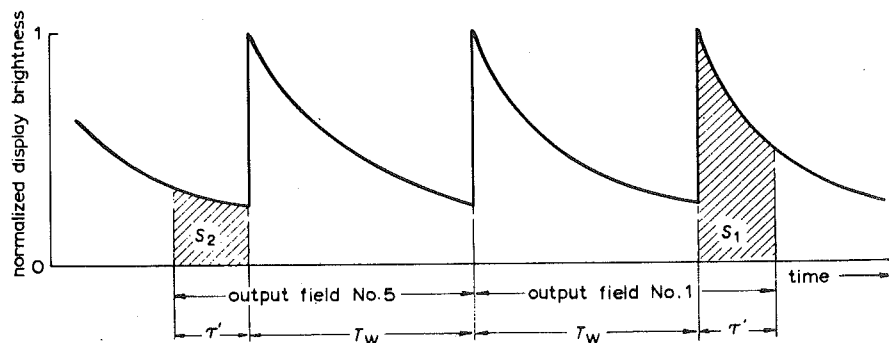


Fig. 7 - The calculation of maximum and minimum outputs, when T_R is greater than T_w

maximum output from a reading field is proportional to the area under one cycle of a display field waveform plus the area S_1 while the minimum is one cycle plus the area S_2 . Let the display and reading field periods again be T_w and T_R respectively. τ , which has been defined as $(T_w - T_R)$ is now negative and it is convenient to let

$$\begin{aligned} \tau' &= T_R - T_w \\ &= -\tau \end{aligned}$$

The display brightness waveform will again be $B(t) = \sum A_r e^{-\alpha_r t}$

$$\text{where } A_r = \frac{\alpha_r}{1 - e^{-\alpha_r T_w}}$$

The area under one cycle is
$$\int_0^{T_w} B(t) dt$$

$$= \sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r T_w}) = \sum \frac{a_r}{\alpha_r}$$

The area S_1 is
$$\int_0^{\tau'} B(t) dt = \sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r \tau'})$$

The area S_2 is
$$\int_{T_w - \tau'}^{T_w} B(t) dt = \sum \frac{A_r}{\alpha_r} e^{-\alpha_r (T_w - \tau')} (1 - e^{-\alpha_r \tau'})$$

The peak-to-peak ripple is the difference between the areas S_1 and S_2 , which is equal to

$$\sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r \tau'}) (1 - e^{-\alpha_r (T_w - \tau')})$$

This is of precisely the same form as the result when the camera field frequency is higher than the display frequency.

The mean of the maximum and minimum output is proportional to the area under one cycle of $B(t)$ plus $\frac{1}{2} (S_1 + S_2)$,

i.e. to
$$\sum \frac{A_r}{\alpha_r} \{ (1 - e^{-\alpha_r T_w}) + \frac{1}{2} (1 - e^{-\alpha_r \tau'}) (1 + e^{-\alpha_r (T_w - \tau')}) \}$$

This gives the ratio of modulation amplitude to the mean of the extreme outputs as

$$\frac{\sum \frac{A_r}{\alpha_r} (1 - e^{-\alpha_r \tau'}) (1 - e^{-\alpha_r (T_w - \tau')})}{\sum \frac{A_r}{\alpha_r} \{ (1 - e^{-\alpha_r T_w}) + \frac{1}{2} (1 - e^{-\alpha_r \tau'}) (1 + e^{-\alpha_r (T_w - \tau')}) \}}$$

This cannot be simplified in the same way as was the expression relating to conversion to a higher field frequency, but the results for an exponential decay characteristic with $\alpha T_w = 1.2/3, 2, 5$, and $6.2/3$ are plotted as the full-line curves in the left-hand half of Fig. 8. (The value $\alpha T_w = 1.2/3$ was chosen so that $1/\alpha = 10$ ms when the display field frequency is 60 c/s. The value $\alpha T_w = 6.2/3$ was chosen so that $1/\alpha = 3$ ms when the display field frequency is 50 c/s).

If the q th reading scan is defined as that which occurs $q\tau'$ after the preceding peak of the illumination cycle, and Q_q is the charge read off at the q th scan, a graph of Q_q against q (or against time) will consist of two exponential parts; for values of q between 0 and 1 the curve rises and is convex upwards, while for values of q greater than one it falls and is concave upwards.

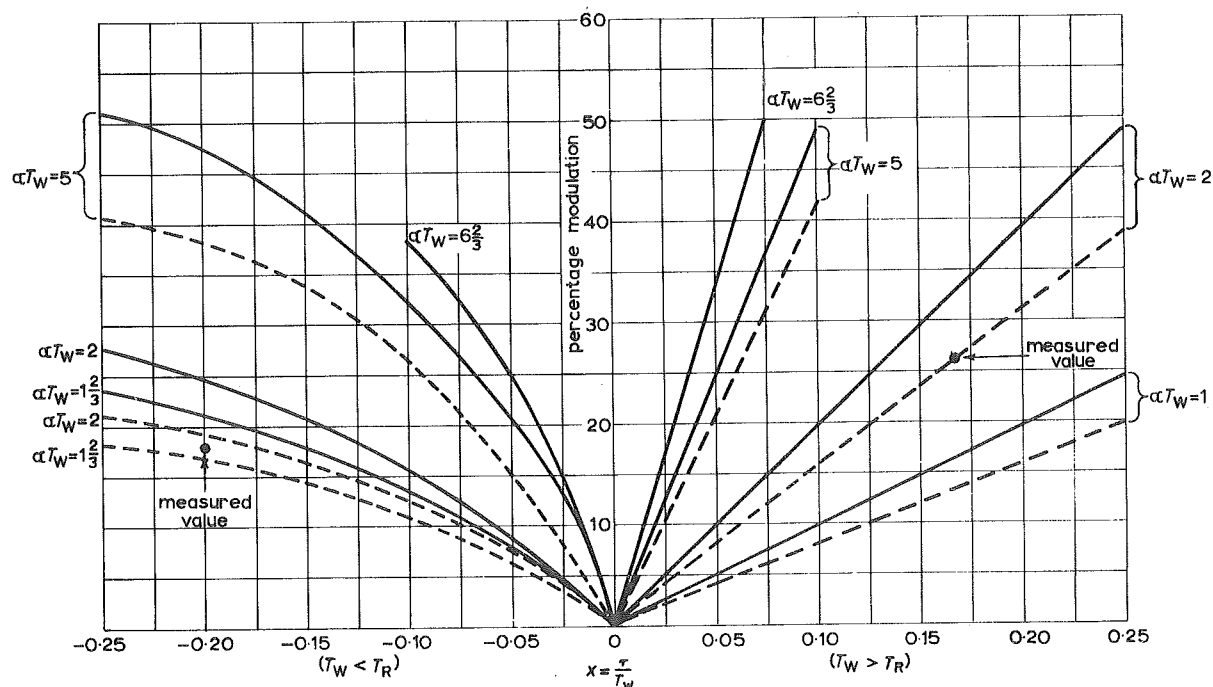


Fig. 8 - Calculated values of percentage modulation - Display tube law $b = Be^{-at}$

T_W Writing field period

T_R Reading field period

(Measured results are taken from a Standards Converter at the Television Centre)

———— Ideal Camera

----- Camera with simplified characteristics

2.3.4. The effects of the storage and discharge characteristics of the camera

The camera characteristics shown in Fig. 4 show that the output resulting from impulsive illumination is a function of the delay between the illumination and the first discharge of an element of the target. However, the effect is relatively small and for a first approximation the change of output with delay will be ignored. This approximation simplifies consideration of the output signal from a camera exposed to a varying illumination.

If a quantity of charge Q is developed at a point of the target during one camera field period then d_1Q is read out at the end of the field, d_2Q at the end of the next field, d_3Q at the field after that, etc., where d_1 , d_2 , and d_3 , etc., are constants. Using this approximation, a camera exposed to varying illumination will then read off at any scan a proportion d_1 of the charge developed in the previous field period plus d_2 of the charge developed between one and two field periods before the scan plus d_3 of the charge developed between two and three fields before the scan. The variation in illumination will cause changes in the components proportional to d_1 and the patterns of these changes will be repeated one field later, at a reduced level, in the components proportional to d_2 and another field later in the components proportional to d_3 .

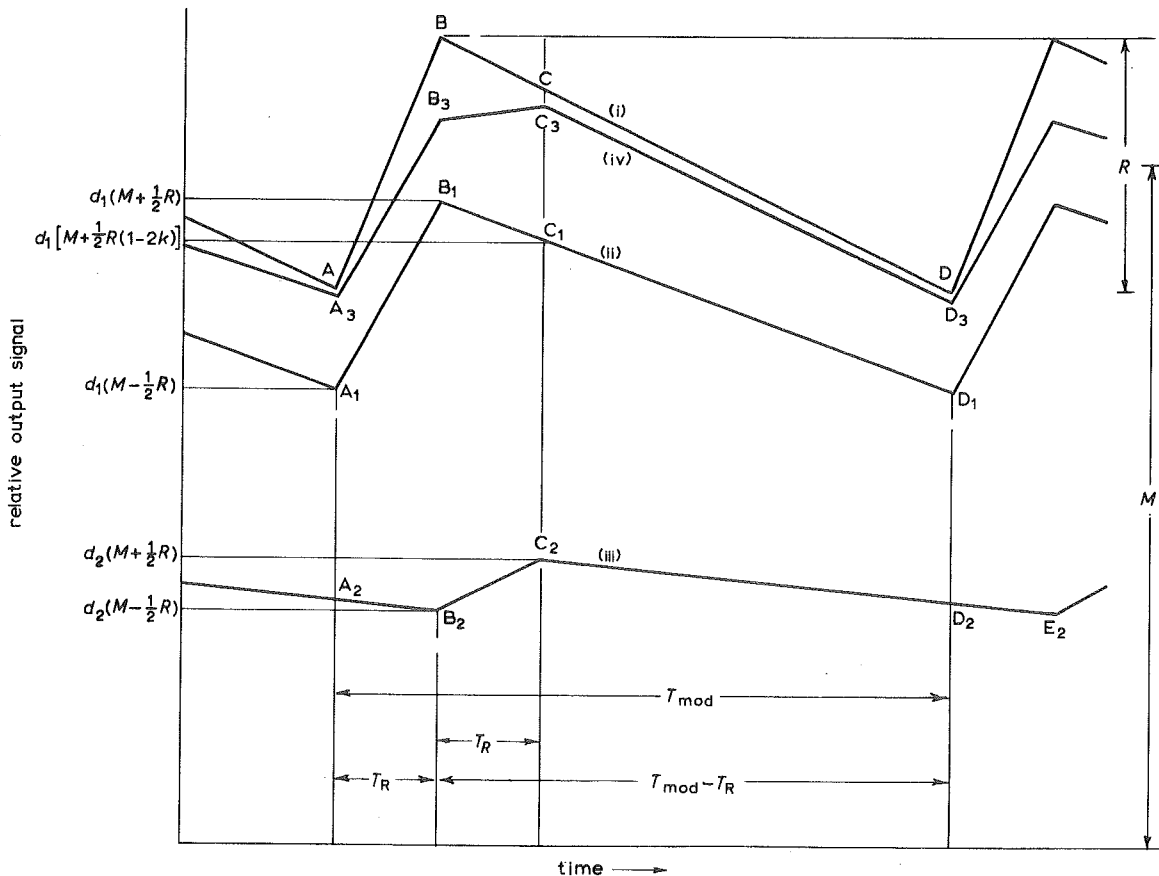


Fig. 9 - The effect of camera discharge characteristics on flicker modulation (simplified characteristics)

- (i) Assumed output from camera with ideal characteristics
- (ii) First-scan component of output from camera with simplified characteristics
- (iii) Second-scan component of output from camera with simplified characteristics
- (iv) The sum of (ii) and (iii)

In Fig. 9 the waveform from an ideal camera has been represented by a linear sawtooth ABD, of maximum excursion R , mean value M , and periodic time T_{mod} . (This waveform is a compromise between the exponential curves which were derived theoretically for conversion to higher and lower field frequencies assuming an exponential characteristic of the display tube phosphor. The linear sawtooth ripple would have resulted if the light output of the phosphor had decayed linearly). This sawtooth waveform may be considered in two parts, a constant component $(M - \frac{1}{2}R)$ plus a component which varies between zero and R . The components of the output from a camera with simplified characteristics will be considered in turn, taking mean values of d_1 and d_2 from Fig. 4, as 0.75 and 0.18 respectively. It is consistent with the measured characteristics of the C.P.S. Emitron tube that the sum $(d_1 + d_2)$ is less than 1.

The component of the output corresponding to d_1 is shown in Fig. 9 as the sawtooth $A_1 B_1 D_1$. The heights of A_1 and D_1 are $d_1(M - \frac{1}{2}R)$, the ordinate of B_1 is

$d_1 (M + \frac{1}{2}R)$. At C_1 , a time T_R after B, the height is

$$d_1 [M + \frac{1}{2}R(1 - 2k)] \text{ where } k \text{ stands for the ratio } \frac{T_R}{T_{\text{mod}} - T_R}$$

The component of output corresponding to d_2 is shown as the sawtooth $B_2 C_2 E_2$, the level at B_2 and E_2 being $d_2(M - \frac{1}{2}R)$, that at C_2 being $d_2(M + \frac{1}{2}R)$ while that at D_2 is $d_2 [M - \frac{1}{2}R(1 - 2k)]$.

Adding these together gives the waveform $A_3 B_3 C_3 D_3$, whose ordinates are:

$$\text{At } A_3 \text{ and } D_3, d_1(M - \frac{1}{2}R) + d_2 [M - \frac{1}{2}R(1 - 2k)] = M(d_1 + d_2) - \frac{R}{2} (d_1 + d_2 - 2kd_2)$$

$$\text{At } B_3, d_1(M + \frac{1}{2}R) + d_2(M - \frac{1}{2}R) = M(d_1 + d_2) + \frac{R}{2} (d_1 - d_2)$$

$$\text{At } C_3, d_1 [M + \frac{1}{2}R(1 - 2k)] + d_2(M + \frac{1}{2}R) = M(d_1 + d_2) + \frac{R}{2} (d_1 + d_2 - 2kd_1)$$

For conversion from 60 c/s to 50 c/s, $k = 0.25$. Substituting the numerical values, the ordinates will be:

$$\text{At } A_3, D_3 \quad 0.93M - 0.42R$$

$$\text{At } B_3 \quad 0.93M + 0.285R$$

$$\text{At } C_3 \quad 0.93M + 0.278R$$

From these it is seen that the trough and peak of the modulation are at A_3 and B_3 . The ripple amplitude is $0.705R$ and the mean of the peak and trough is $0.93M - 0.07R$ so the resulting ripple-to-mean ratio is

$$\frac{0.705 R/M}{0.93 - 0.07 R/M}$$

The value of R/M for a perfect camera was calculated as 0.185, so the formula gives the ratio for the simplified camera as

$$\frac{0.705 \times 0.185}{0.93 - 0.07 \times 0.185} = 0.15$$

where the computations gave 0.16.

For conversion from 50 c/s to 60 c/s where $k = 0.20$ the heights of the main points of the modulation characteristic will then be:

$$\text{At } A_3, D_3 \quad 0.93M - 0.429R$$

$$\text{At } B_3 \quad 0.93M + 0.285R$$

$$\text{At } C_3 \quad 0.93M + 0.315R$$

The maximum value is now at C_3 , the ripple amplitude being $0.744R$ and the mean $0.93M - 0.057R$.

The value of R/M for a perfect camera was calculated as 0.29 so the formula gives the ratio for the output of a simplified camera as

$$\frac{0.744 R/M}{0.93 - 0.057 R/M} = 0.24$$

where the computations gave 0.25 .

Similar calculations, based on the same assumed values of d_1 and d_2 , were used to derive the modulation percentages for a 'simplified' camera from those of a perfect camera which had been plotted as solid lines in Fig. 8. These derived results are also plotted in Fig. 8 as dashed lines.

3. THE MEASUREMENT OF MODULATION AMPLITUDE

An image-transfer standards converter at the Television Centre was set up with a plain raster of normal size on its display tube and the camera was adjusted for normal operation. The output from the camera control unit was displayed on an oscilloscope and the waveform was photographed. This was done first with the display scanning at 60 fields per second and the camera scanning at 50 fields per second and then with the two field frequencies interchanged. From the photographs of the waveforms measurements were taken of the output from one point of the camera raster on each of the fields of a modulation cycle. The results are plotted as curves (c) in Figs. 10 and 11.

4. DISCUSSION OF RESULTS

The modulation amplitudes given in this report are expressed as percentages of the mean of the maximum and minimum outputs, i.e. if V_1 is the maximum output and V_2 is the minimum output during a cycle of modulation, the modulation percentage is taken as

$$\frac{(V_1 - V_2)}{(V_1 + V_2)/2} \times 100\%$$

(Note that when this convention is used a converter output which falls to zero at a point in the modulation cycle is described as having a modulation of 200%).

The results of the calculations and measurements may be summarized as follows:

PERCENTAGE MODULATION				
	(a)	FIELD FREQUENCY CONVERTED FROM 50 c/s TO 60 c/s	(b)	FIELD FREQUENCY CONVERTED FROM 60 c/s TO 50 c/s
Calculated:				
	Ideal camera	29		18.5
	Practical camera	25		16
Measured:				
		26		18

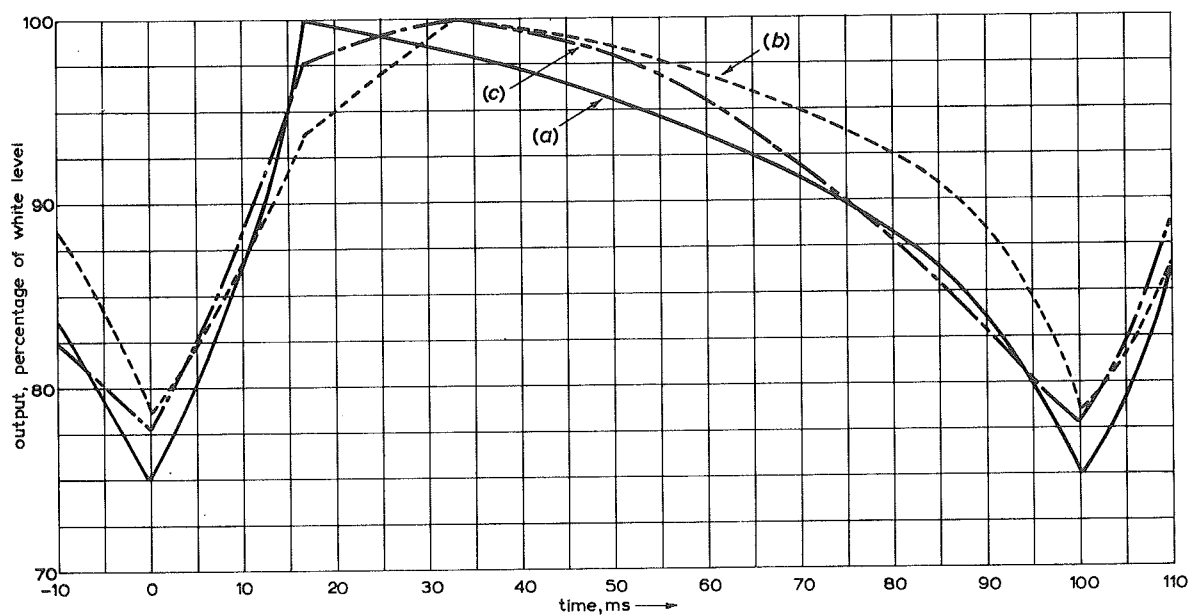


Fig. 10 - 10 c/s flicker modulation waveforms, 50 c/s to 60 c/s conversion

- (a) Calculated, perfect camera
- (b) Calculated, practical camera
- (c) Measured

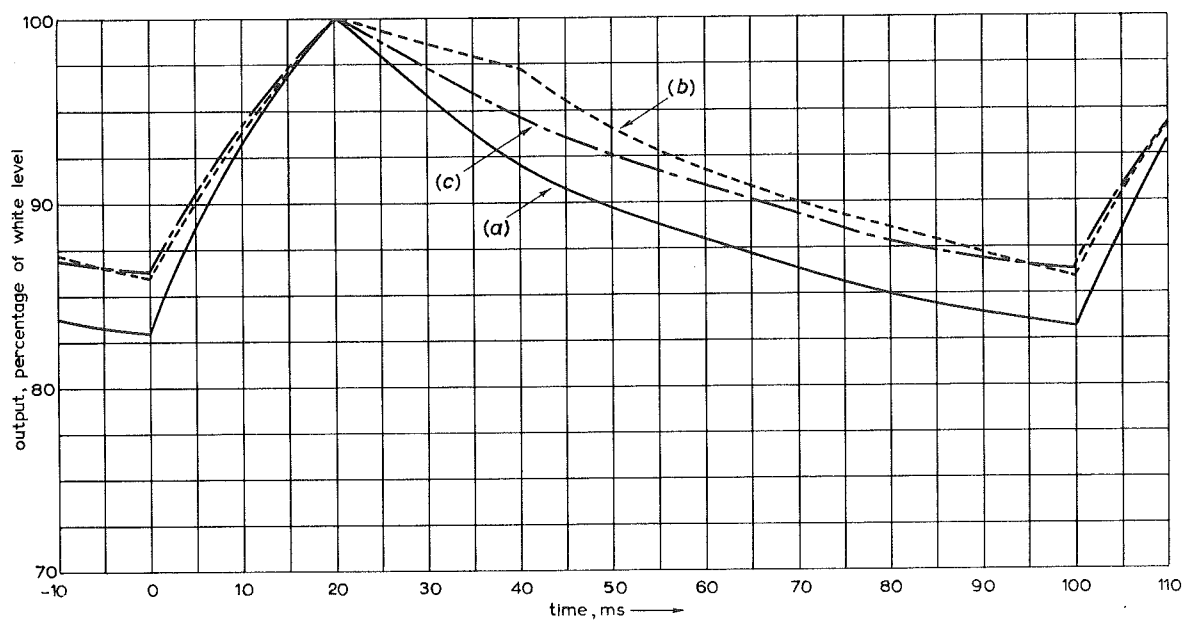


Fig. 11 - 10 c/s flicker modulation waveforms, 60 c/s to 50 c/s conversion

- (a) Calculated, perfect camera
- (b) Calculated, practical camera
- (c) Measured

The camera-tube characteristics used in section 2 were obtained by measuring one particular camera-tube and it was not possible to use the same tube for the experimental determination of flicker modulation. Camera-tube storage characteristics are somewhat variable from tube to tube and depend to some extent upon the operating conditions. In view of this and the limited measurement accuracy, there is a reasonable agreement between the calculated and measured modulation waveforms.

5. CONCLUSIONS

The methods of calculation of flicker modulation described in this report give results which are close to those obtained by measuring a typical image-transfer standards converter operating between field frequencies of 60 c/s and 50 c/s.

Curves have also been produced showing the flicker modulation which may be expected when converting between other field frequencies.

6. REFERENCES

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